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POLAR-TROPICAL INTERACTIONS INVOLVING THE ROSS SEA SECTOR OF ANTARCTICA

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1. INTRODUCTION

Previous studies find a strong signal of the El Niño-Southern Oscillation (ENSO) phenomenon in Antarctic climate (e.g., Smith and Stearns 1993). Moreover, researchers have looked to Southern Hemisphere (SH) fields for precursors to El Niño events (e.g., van Loon and Shea 1987). The Ross Sea is a region where the high southern latitude linkage to ENSO may be particularly large (Bromwich et al. 1998a,b; Bromwich et al. 2000). Recent work suggests that there is a corridor in the West Pacific region that allows latitudinal communication from the Antarctic to the Arctic (Hines et al. 2001). Teleconnections between Antarctic climate and tropical phenomena such as ENSO and intraseasonal oscillations (ISOs) could occur through this corridor. Here we consider whether the strong ENSO signal in the Southern Ocean and Marie Byrd Land can be related to decadal ENSO change and precursors to ENSO events.

2. WEST ANTARCTIC PRECIPITATION

In remote areas of the high southern latitudes, the information obtained by direct measurements of atmospheric and surface parameters is limited not only by the accuracy of the collection methods employed, but also by the sparse observational network in place. Snow accumulation closely approximates precipitation minus evaporation/sublimation (P-E) over most parts of Antarctica. Global analysis models allow the atmosphere to be studied with a rigor that would be extremely difficult and expensive to match using direct observational approaches.

Previously, Cullather et al. (1996) presented a review of literature relating atmospheric circulation over Antarctica to ENSO phenomenon. They computed P-E via the moisture flux convergence (MFC) using operational analyses from European Centre for Medium-Range Weather Forecasts (ECMWF) for the South Pacific sector of West Antarctica bounded by 120ºW to 180º, 75ºS to 90ºS. These calculations have been updated through May 2000 in Fig. 1. The calculated P-E is correlated with the Southern Oscillation Index (SOI) from the early 1980s through 1990. The relation becomes anticorrelated after 1990, a period corresponding to a significant increase in P-E for the Antarctic continent. The relationship is robust as the continually expanding time series demonstrates and is supported by a moderate amount of surface-based observations (Bromwich et al. 2000). Note that only qualitative conditions are resolved prior to 1985 because of ECMWF WMO analysis shortcomings.

Analyses produced by the National Centers for Environmental Prediction (NCEP) in conjunction with NCAR (NNR) are used to describe annual 500 hPa anomalies for strong El Niño events of 1982/1983 and 1997/1998. The anomalies for these years centered on the SOI minimums are relative to the average for 1979-1999.

Figure 1 shows that the 1997/1998 event is comparatively wet in the West Antarctic sector during the anti-correlated phase of MFC with the SOI. By contrast, the strong El Niño event of 1982/1983 is relatively dry and occurs in the positively correlated phase between MFC and the SOI. Cullather et al. (1996) note that the SOI modulation of MFC is a consequence of changes in the mean circulation, and thus should be reflected in the mean geopotential height fields. The equivalent barotropic structure of the Antarctic atmosphere means that similar behavior should be present at many levels, for example, at sea level and at the 500 hPa level.

Figure 2 presents the annual 500 hPa anomalies for the 1982/1983 and 1997/1998 El Niño events. Away from Antarctica, the height anomalies are similar (consistent with van Loon and Shea 1987), but are quite different over the West Antarctic sector. During 1997/1998, the anomalous circulation steers moisture from the north into the sector to support enhanced precipitation. This circulation is absent, by contrast, during 1982/1983 and the area is overlain by a weak high, consistent with the drier conditions for this El Niño event.

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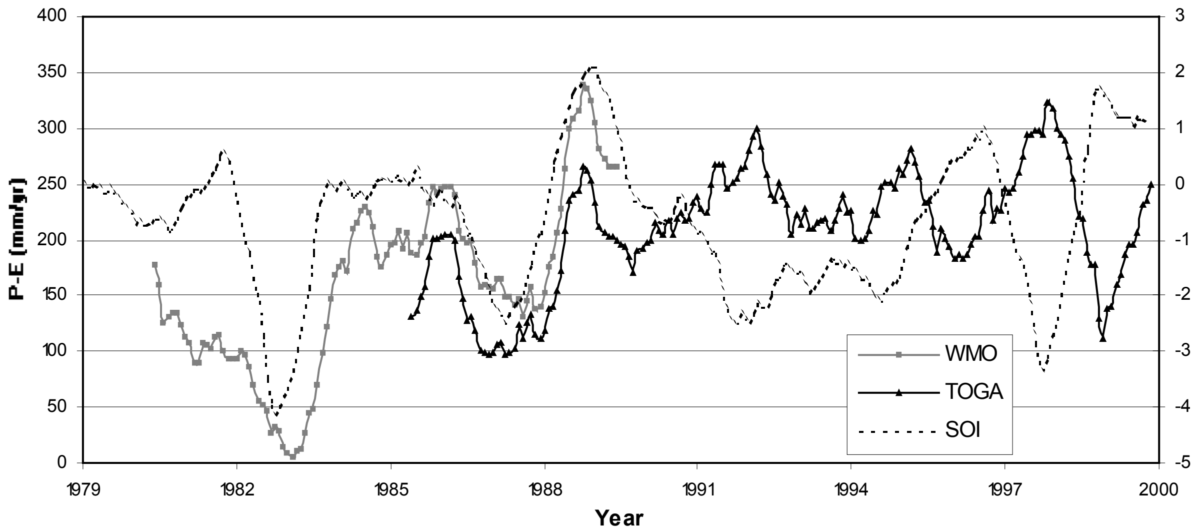

Figure 1. Annual running mean of P-E (left scale) from monthly MFC values for the West Antarctic sector calculated from ECMWF WMO and TOGA data (updated through May 2000) along with the SOI (right scale).

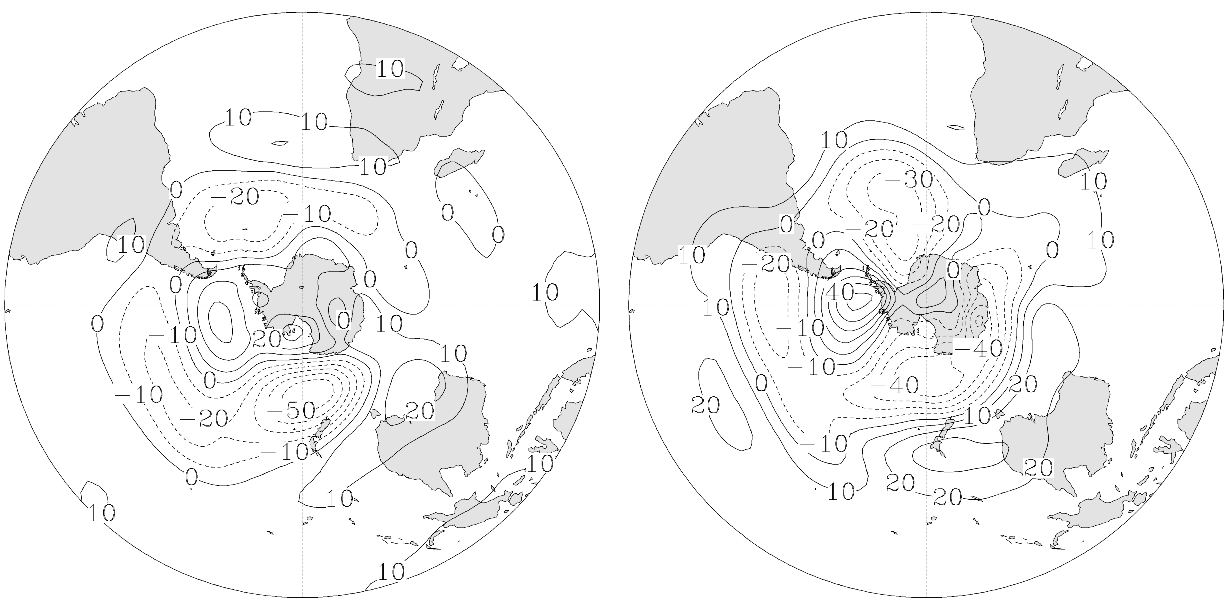

Figure 2. Annual 500 hPa geopotential height anomalies (geopotential meters, gpm) for (a) July-June of the dry 1982/1983 El Niño conditions, and (b) July-June of the 1997/1998 wet El Niño conditions. Contour interval is 10 gpm.

3. WEST PACIFIC TELECONNECTION

Sensitivity studies with global climate models (GCMs), including the NCAR Community Climate Model versions 2 and 3 (CCM2 and CCM3), have revealed a teleconnection between Wilkes Land and the Ross Sea to the East Asian monsoon during the late austral winter/boreal summer. A very similar phenomenon is found in observational studies as Fig. 1 in Hines and Bromwich (2001, this volume) displays the corresponding teleconnection during August in the NNR. The surface pressure field shows that anticorrelated centers of the teleconnection reside over southeastern Australia and Wilkes Land in the SH. Another primary pressure anomaly, anticorrelated to the Wilkes Land component, is located over the western North Pacific Ocean in the

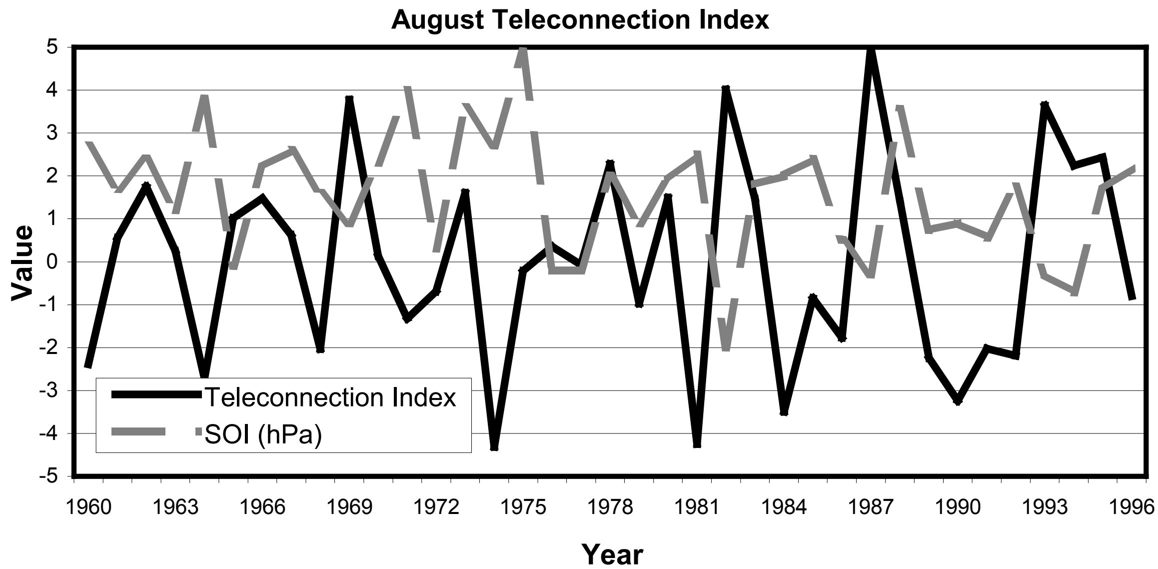

Figure 3. Time series of the August teleconnection index (solid line, hPa) and the August Southern Oscillation Index (dashed line,hPa).

Northern Hemisphere. Additional teleconnection anomalies are also found over the Aleutian Islands to the north and near the Antarctic Peninsula to the east. The GCM version of the teleconnection can be excited by a variety of Antarctic forcings such as large sea ice anomalies (Bromwich et al. 1998a,b) and modified cloud-radiation interactions over Antarctica (Lubin et al. 1998), suggesting that these longitudes are prime areas for equatorward propagation of atmospheric long waves generated over Antarctica. Furthermore, the teleconnection is linked to the tropical intraseasonal oscillation (ISO, Hines and Bromwich 2001), and resembles the Pacific response pattern for the ISO found by Kiladis and Mo (1998).

A monthly teleconnection index has been defined based upon the three primary teleconnection anomalies in the West Pacific region. The index is calculated with a weighted sum of surface pressures, including Dumont d'Urville, Antarctica observations (**DMNT**) at 66.7ºS, 140.0ºE, an NNR grid point in the Australia-New Zealand sector of the SH mid-latitudes (**ML**) at 40ºS, 150ºE, and an NNR grid point offshore from China in the Northern Hemisphere subtropics (**NHST**) at 25ºN, 125ºE,

$$\textbf{INDEX} = \textbf{0.462 NHST} + \textbf{0.302 ML} - \textbf{0.171 DMNT} - \textbf{589},$$

where the input is in hPa, and the value 589 is subtracted to normalize the index. The index allows us to define "positive" and "negative" phases. The intensity of a particular phase of the teleconnection is proportional to the magnitude of the index. The August values of the teleconnection index from 1960-1996 are shown in Fig. 3. The August teleconnection appears to have variability on ENSO time scales. Extremes of the SOI often correspond to extremes of the teleconnection index, though not necessarily in a consistent pattern. There is a bias, however, towards positive phases of the teleconnection coinciding with negative values of the SOI. This is physically consistent as ridging in the Australian region is common during El Niño events (negative SOI) and contributes positively to **ML** and hence to the teleconnection index. The correlation of the August teleconnection index to the 3-month average of the SOI of the same austral winter (June. July and August) is-0.38.

Interestingly, from 1980-1993 in Fig. 3, an extreme of the teleconnection index is frequently followed 1 year later by an extreme of the same sign in the SOI. In fact, the correlation of the teleconnection index during August to the 3-month average (July, August, September) SOI for 12 months later is 0.41. The ability of the teleconnection index as a precursor to SOI extremes may be linked to pressure anomalies near the Tasman Sea. van Loon and Shea (1987) find that development of the Tasman trough is a precursor to El Niño warm events. In their May, June, July composite precursor ("year -1") field, they show a Tasman trough centered near 40ºS, 150ºE and a high over the central Pacific near 40ºS, 130ºW. Consistent with the pattern of the high latitude mode/Antarctic Oscillation, higher pressure is also present near the Antarctic coast south of Australia. These SH anomalies match those of the negative phase of West Pacific teleconnection. The Tasman trough is still present, although weaker, in van Loon and Shea's August, September and October composite. By the austral winter of the following year, their SH pattern has reversed with a high in the Australian sector and a low over the central Pacific. The latter pattern is consistent with a negative SOI (Tahiti - Darwin). Thus, the change in sign from a positive correlation when the

August teleconnection index leads the SOI by about one year to a negative correlation for the same austral winter is more or less consistent with the SH pattern reversal found by van Loon and Shea (1987) during the development of El Niño warm events. This suggests that the West Pacific teleconnection shown in Fig. 1 of Hines and Bromwich (2001) may play a role in the development ENSO events, and furthermore, may be useful as a precursor.

While the West Pacific teleconnection was found in monthly-mean fields for late austral winter, similar phenomena might be occurring from autumn to spring. Kiladis and Mo (1998) show a filtered response field to the tropical ISO (the Madden-Julian Oscillation) that resembles the August teleconnection. This is intriguing as there is currently considerable debate among tropical climatologists as to the role of the ISO in the development of ENSO events.

4. CONCLUSIONS

Diagnostic studies of the precipitation rate over Marie Byrd Land adjacent to the Ross Ice Shelf have shown a close, but bimodal relationship with the SOI from the early 1980s to today. The bimodal behavior of the time-average circulation over the Ross Sea is consistent with the precipitation variations over Marie Byrd Land, but the hemispheric-scale circulation is unimodal as shown by van Loon and Shea (1987). This indicates that the mid-tropospheric circumpolar vortex that is usually centered to the northeast of the Ross Ice Shelf is strongly but locally modulated by the SOI. The Ross Sea sector is due south of the tropical Pacific Ocean sector where SST changes associated with ENSO are most pronounced.

Studies with GCMs and observational analyses have revealed a West Pacific teleconnection between Wilkes Land adjacent to the Ross Sea and the East Asian monsoon during the late austral winter/boreal summer. The surface pressure field shows that the primary centers of the teleconnection reside over southeastern Australia and Wilkes Land in the SH and over the western North Pacific Ocean in the Northern Hemisphere. For the positive phase, positive pressure anomalies are found over Australia and the North Pacific, and negative anomalies over and adjacent to Wilkes Land. This teleconnection can be excited in GCMs by a variety of Antarctic forcings (such as large sea ice anomalies and modified cloud-radiation interactions over Antarctica), suggesting that these longitudes are prime areas for equatorward propagation of atmospheric long waves generated over Antarctica. Observational studies with the NNR have shown a similar teleconnection pattern in August that has variability on ENSO time scales, and is linked to the tropical intraseasonal oscillation. It is significant that the negative phase of the teleconnection often precedes negative values of the SOI by about one year as van Loon and colleagues note that troughing in the Tasman Sea is often precedes development of El Niño events.

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